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COMBUSTION STABILITY LIMITS FOR SWIRL-JET COMBUSTOR MODULES COMBINING AIR-SWIRL AND IMPINGING-JET ATOMIZATION OF ASTM A-1 FUEL

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16. Abstract

Eight different designs of swirl-jet combustor modules were tested in a 3.25-inch- (8.25-cm-) diameter duct with 600° F (589 K) air at reference velocities of 200 to 500 feet per second (61 to 153 m/sec) and atmospheric pressure. The highest ratio of rich-to-lean combustion stability limits was obtained with a module consisting of a single air swirler, a single pair of 180° impinging fuel jets (0.076-cm diameter.), and a coiled-strip-type flame stabilizer. Results were considerably better than those obtained in recent investigations using swirl-can combustor modules.

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Some of these studies (ref. 3) have shown that various methods of distributing the fuel in the module did not appreciably affect combustion stability limits. This appeared to be due to the fact that the fuel distributor was located upstream of the air swirler, and most of the fuel was sprayed out near the tips of the swirler blades. An approach toward obtaining a more uniform distribution of fuel across the module cross section was tested in this investigation. To do this, the air swirler was placed upstream of the fuel injection point. Pairs of 180° (opposing) impinging fuel jets were used to inject the fuel at the module axis. This technique produces a point source of fuel on the axis from which the fuel could then be evenly distributed over the module cross section.

The purpose of this investigation was to obtain combustion stability-limit data for eight different designs of swirl-jet combustor modules. The term swirl-jet was used to describe the modules since they used the combined effect of air-swirl and impinging-jet atomization of the ASTM A-1 fuel. Swirl-jet combustor modules blocking approximately 40 percent of the area of a 3.25-inch- (8.25-cm-) diameter duct were tested with airstreams preheated to 600° F (589 K). Results were then compared with those obtained in previous studies using swirl-can combustor modules.

APPARATUS AND PROCEDURE

The 3.25-inch- (8.25-cm-) diameter test section shown in figure 1 was used to test various designs of a swirl-jet combustor module. Each module blocked approximately 40 percent of the duct. ASTM A-1 fuel was burned in the modules with airflow provided by the laboratory supply system. A direct-fired (vitiating) preheater burning natural gas fuel preheated the airstream to 600° F (589 K), and a J-47 combustor can and several sets of screens were used to smooth out the airstream temperature profile. The inlet-air temperature to the module was measured with an iron-constantan thermocouple located directly upstream of the test module. Airflow rates were measured with a sharp-edged orifice installed according to ASME specifications, and fuel flow rates were measured with a turbine-type flowmeter.

The test module was centered in the duct and supported by the fuel tube as shown in figure 1. Combustion stability-limit data were obtained by setting the airflow rate at a given reference velocity and slowly increasing (or decreasing) the fuel-flow rate until a rich (or lean) blowout occurred. A reference velocity range of 200 to 500 feet per second (61 to 152.5 m/sec) was used in these tests.

Fuel-air ratios at the limiting fuel flow or blowout condition were calculated from the respective weight flows of fuel and air. Calculations of the reference velocity for the test module were based on the cross-sectional area of the test section and the inlet-airstream temperature of 600° F (589 K) and a static pressure of 1 atmosphere.

A schematic drawing of three different designs of the swirl-jet combustor module is shown in figure 2. Fuel was injected by means of a pair of 180° impinging jets into the rotating airflow produced by the swirler (or multiple swirlers) where it was atomized and then burned as it passed through the flame stabilizer or coiled strip. A description is given in table 1 of the eight different designs of swirl-jet combustor modules tested in this investigation.

RESULTS AND DISCUSSION

Combustion stability-limit data were obtained for eight different swirl-jet combustor module designs. In the first portion of this study, the effect of the number of air-swirlers (single, double, and triple) on combustion stability limits was determined. In each of the three designs, single pairs of 180° impinging jets were used to inject the fuel into the combustor modules. In the second series of tests, the effect of fuel injector location on combustion stability limits was tested; four pairs of 90° impinging jets were used to distribute the fuel in the combustor module. In the final series of tests, the effect of flame stabilizer design on combustion stability limits was investigated. Four types of flame stabilizers were tested; namely, a coiled strip, a coiled tube with a solid cone in the center, a tube bundle, and a radial V-gutter.

Effect of Multiple Air-Swirlers on Combustion Stability Limits

Combustion stability-limit data were obtained for three types of swirl-jet combustor modules (models 1, 2, and 3) which utilized single, double, and triple air swirlers, respectively. As shown in figure 2, the air swirlers were mounted upstream of a single pair of 180° impinging jets (0.076-cm-diam. orifices), and a coiled-strip-type flame stabilizer was mounted downstream of the impinging jets. A comparison of lean and rich combustor stability-limit data for the three modules is given in figure 3. This figure shows that the swirl-jet combustor module (model 1) with a single air swirler gave the best results at low fuel-air ratios.

Another comparison was made in which the ratio of rich-to-lean combustion stability-limits was plotted against the reference velocity as shown in figure 4. On this basis of comparison, the swirl-jet combustor module with the single air-swirler performed considerably better than the modules with multiple air swirlers. This result was attributed to the multiple air swirlers producing more mixing of the airflow which made it difficult to stabilize the flame at low fuel-air ratios. Figure 4 also shows that the value of the ratio of rich-to-lean combustion stability limits was considerably higher for the swirl-jet combustor module with a single air-swirler than it was for the swirl-can-type

combustor module tested in reference 3. As discussed in reference 3, this ratio is useful in comparing the performances of combustors under severe operating conditions.

Effect of Fuel Injector Location on Combustion Stability Limits

The swirl-jet combustor module (model 4) that was designed for this test is shown on figure 5. The module consisted of a single air swirler, four pairs of 90° impinging fuel jets (0.038-cm-diam. orifices) near the module wall, and a flame stabilizer with a 30° cone half-angle and a coiled strip. As shown in figure 6, combustion stability-limit data for the model 4 module indicate that fuel injection near the wall gave fairly good lean blowout limits. However, rich blowout limits were considerably poorer than those shown in figure 3 for the model 1 module.

A comparison of the ratio of rich-to-lean combustion stability limits for the models 1 and 4 modules is shown in figure 7. From this comparison it is evident that fuel injection with a single pair of 180° impinging jets near the module axis gave the best results. This could be attributed to better fuel distribution being obtained with fuel spreading from a point source near the module axis rather than with fuel being distributed from multiple sources near the module wall.

Effect of Flame Stabilizer Design on Combustion Stability Limits

The four types of flame stabilizers shown in figure 8 were tested to determine the effect of flame stabilizer shapes on combustion stability limits. The combustor module used to test the flame stabilizers is shown in figure 9. The module consisted of a double air swirler, a pair of 90° impinging jets at the module axis, and the flame stabilizer. Results from these tests are given in table II.

The best ratio of rich-to-lean combustion stability limits was obtained with the coiled-strip-type flame stabilizer. The tube bundle and radial V-gutter types gave poor results on this basis of comparison. This result appeared to be due to their opposing the rotation of the air stream produced by the air swirlers. On the other hand, the coiled strip did not oppose the rotation of the air stream since it was coiled in the same direction of rotation. Thus, the coiled strip produced good results as a flame stabilizer. A comparison of the ratio of rich-to-lean combustion stability limits, at a reference velocity of 200 feet per second (61 m/sec), is given in table I for all of the modules tested in this investigation.

SUMMARY OF RESULTS

Combustion stability-limit data obtained by burning ASTM A-1 fuel in eight different swirl-jet combustor modules were compared and the results were as follows:

1. The best results based on the ratio of rich-to-lean combustion stability limits were obtained with a swirl-jet combustor module consisting of a single air swirler, a single pair of 180° impinging jets (0.076-cm-diam. orifices) at the module axis, and a coiled-strip-type flame stabilizer. The results were considerably better than those obtained in recent investigations of swirl-can combustor modules.

2. Tests utilizing four pairs of 90° impinging jets (0.038-cm-diam. orifices) to distribute the fuel near the module wall gave poorer ratios of rich-to-lean combustion stability limits than those obtained by injecting fuel at the module axis with a single pair of 180° impinging fuel jets.

3. Flame stabilizers such as radial V-gutters and tube bundles appeared to straighten out the rotating flow produced by the air swirlers and gave relatively low values of the ratio of rich-to-lean combustion stability limits. The best results based on this ratio were obtained with a coiled-strip-type flame stabilizer which was coiled in the same direction of rotation as that produced by the air swirler.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, November 30, 1970,
720-03.

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2. Niedzwiecki, Richard W.; and Moyer, Harry M.: Performance of a 48-Module Swirl-Can Turbojet Combustor Segment at High Temperatures Using ASTM-A1 Fuel. NASA TN D-5597, 1969.

3. Briehl, Daniel C.; and Ingebo, Robert D.: Effect of Fuel Distribution and Flame Stabilization Techniques on the Performance of Single Swirl-Can Combustor Modules Burning ASTM A-1 Fuel. NASA TM X-2185, 1971.

TABLE I. - DESCRIPTION OF MODULES AND PERFORMANCE COMPARISON

AT REFERENCE VELOCITY OF 200 FEET PER SECOND (61 M/SEC)

Module model	Air swirler	Impinging jet fuel injectors	Jet impingement angle, deg	Flame stabilizer	Ratio of rich-to-lean combustion stability limits
1	Single	1 pair at axis	180	Coiled strip	26.9
2	Double	1 pair at axis	180		11.8
3	Triple	1 pair at axis	180		9.6
4	Single	4 pairs at wall	90		13.7
5	Double	1 pair at axis			10.8
6				Coiled tube with solid cone center	5.1
7				Tube bundle	3.1
8				Radial V-gutter	3.1

TABLE II. - MODULE PERFORMANCE FOR FOUR DIFFERENT

FLAME STABILIZER DESIGNS AT REFERENCE VELOCITY

OF 200 FEET PER SECOND (61 M/SEC)

Module model	Type of flame stabilizer	Combustion stability limits		
		Lean	Rich	Ratio of rich-to-lean
5	Coiled strip	0.0042	0.0453	10.8
6	Coiled tube with solid cone center	.0100	.0510	5.1
7	Tube bundle	.0081	.0248	3.1
8	Radial V-gutter	.0123	.0383	3.1

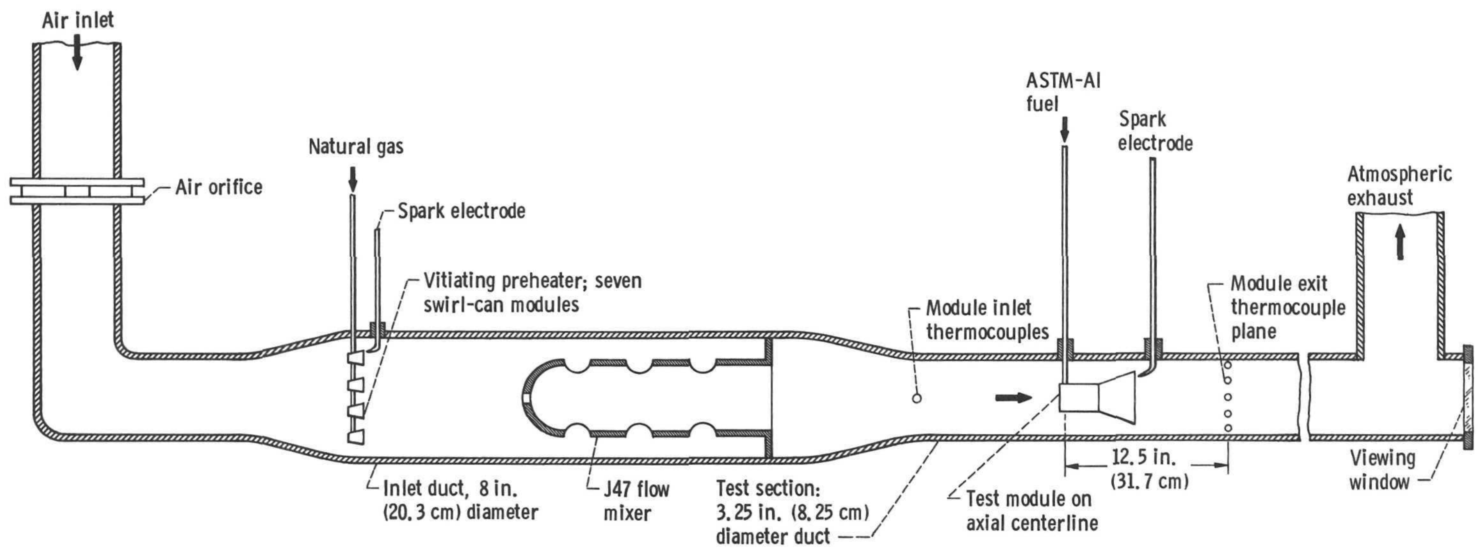
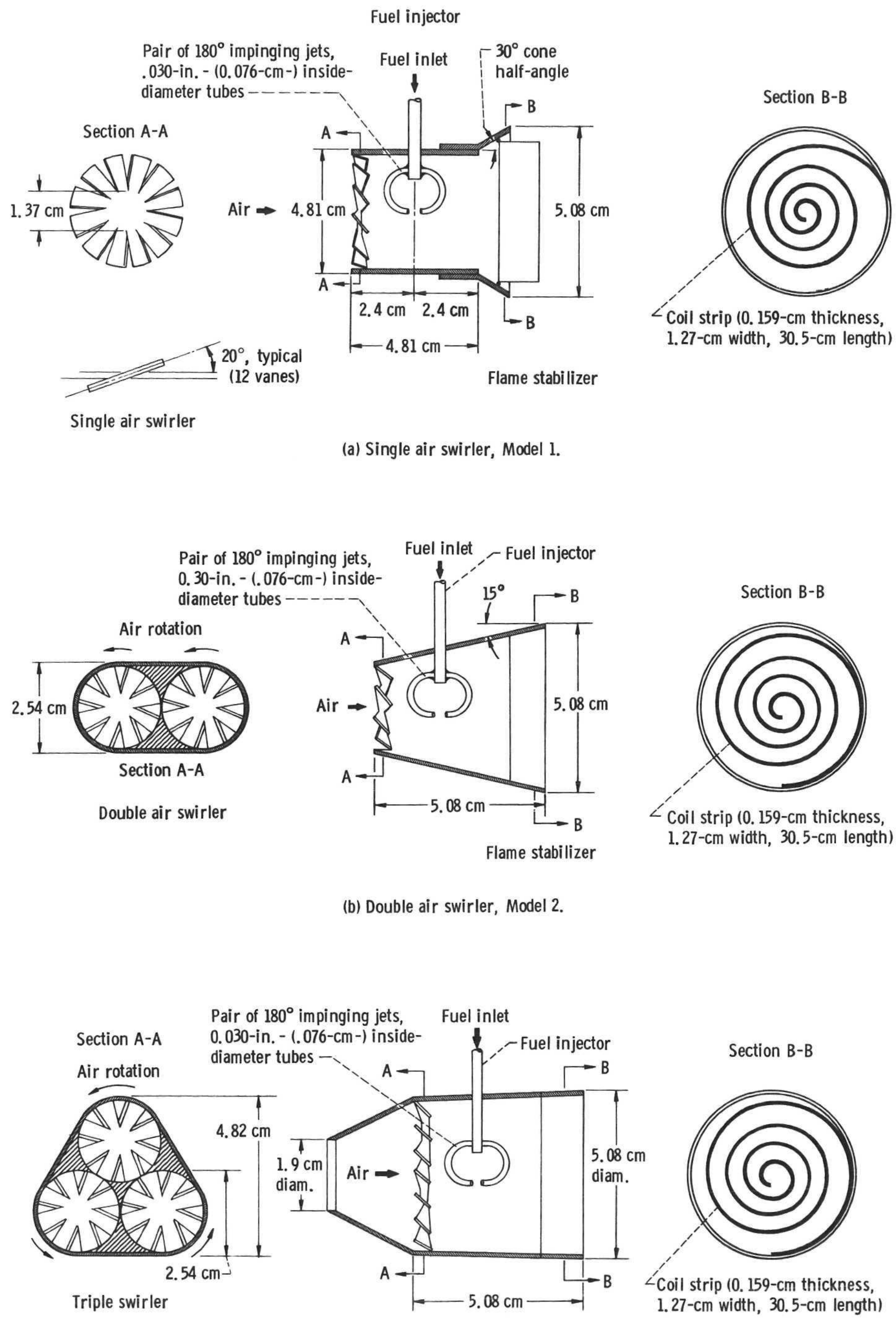


Figure 1. - Schematic diagram of combustion test facility.



(a) Single air swirler, Model 1.

(b) Double air swirler, Model 2.

(c) Triple air swirler, Model 3.

Figure 2. - Swirl-jet combustor modules utilizing air swirlers, pair of 180° impinging fuel jets, and flame stabilizer with 30° cone half-angle and a coiled strip.

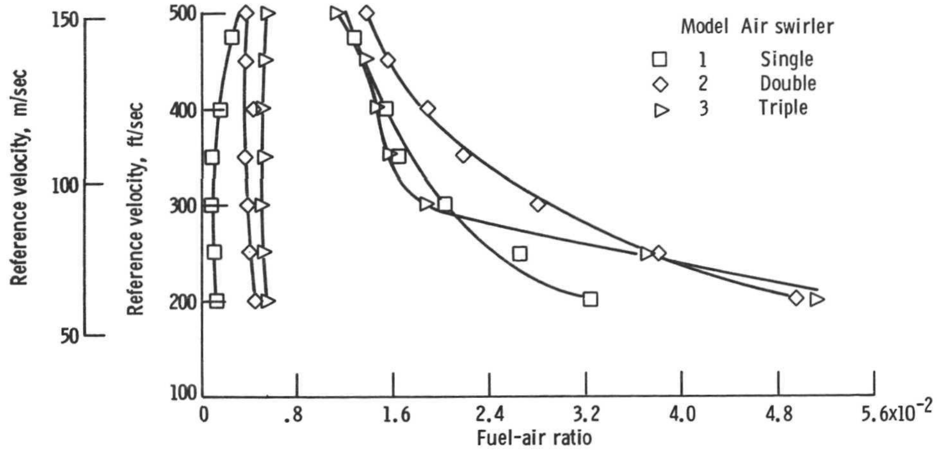


Figure 3. - Comparison of combustion stability limits for modules with single and multiple air swirlers.

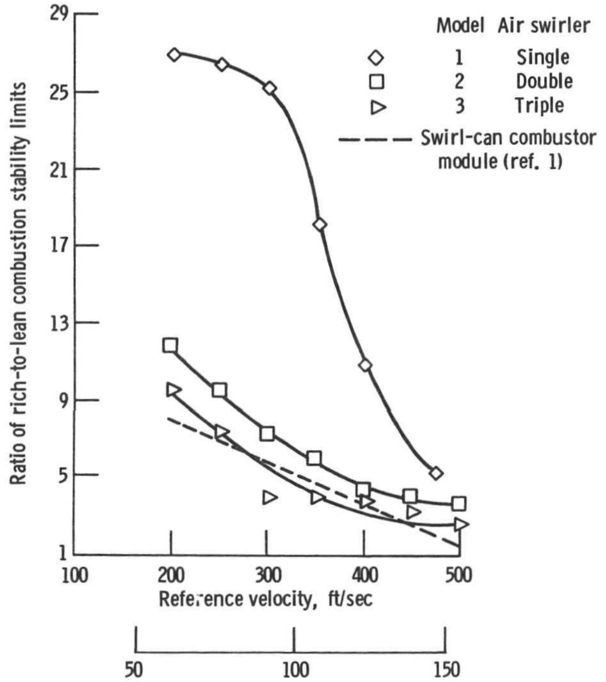


Figure 4. - Comparison of ratios of rich-to-lean combustion stability limits for modules having single and multiple air swirlers with that of swirl-can combustor module.

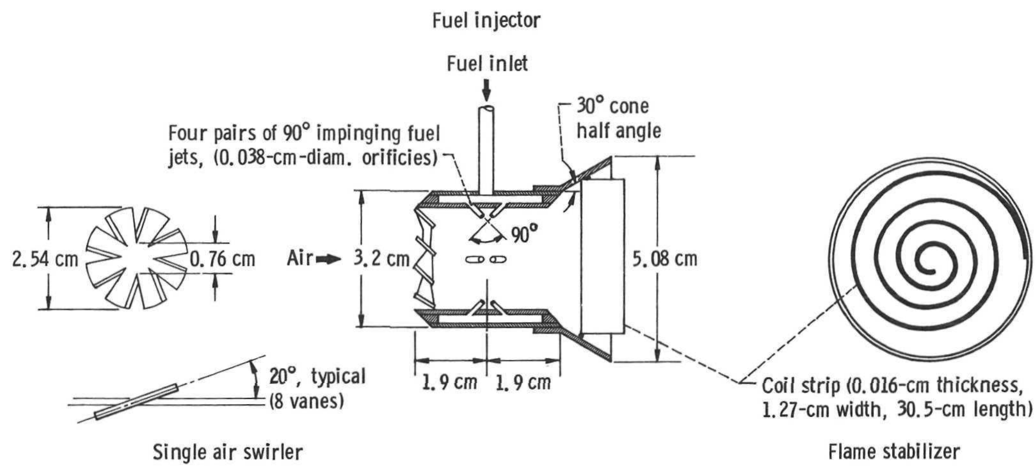


Figure 5. - Swirl-jet combustor module (model 4) using a single air-swirler, four pairs of 90° impinging fuel jets near the wall, and a flame stabilizer with a 30° cone half-angle and a coiled strip.

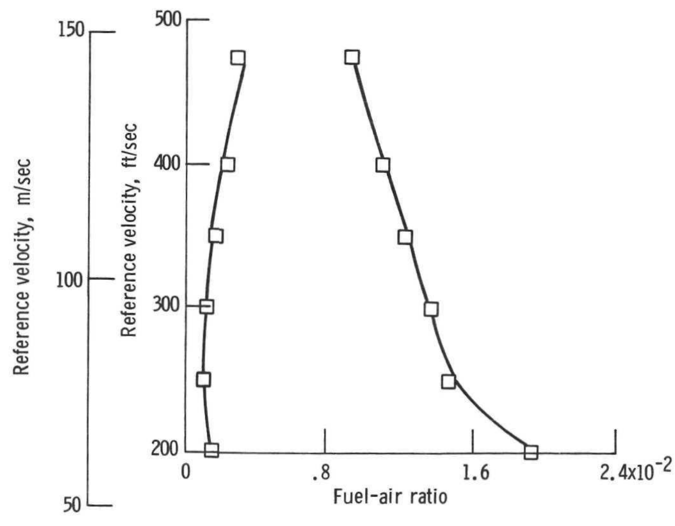


Figure 6. - Combustion stability limits for model 4 module with fuel injection near module wall.

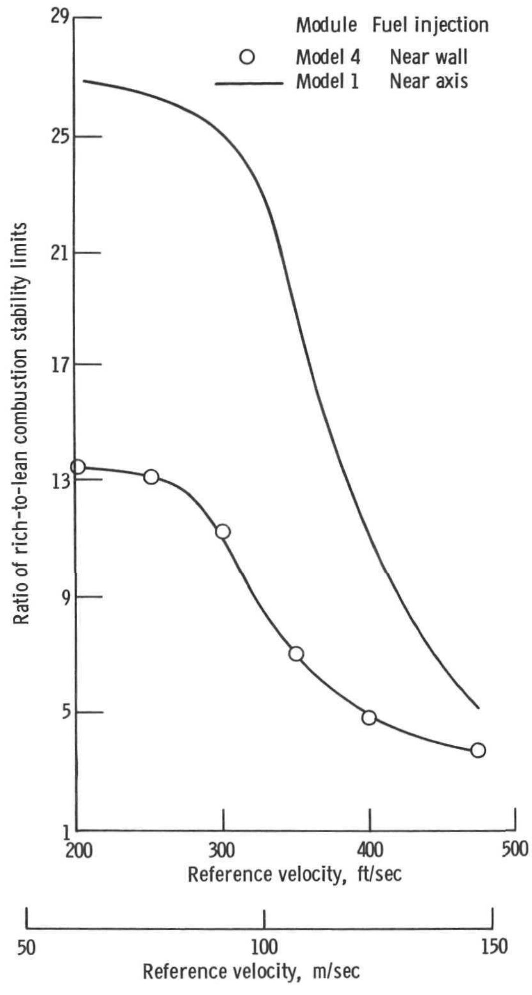
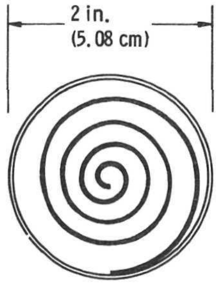
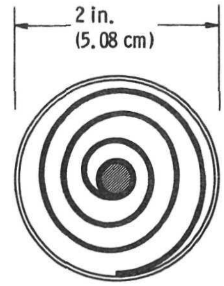


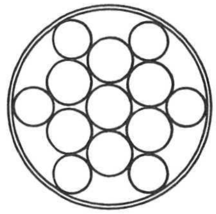
Figure 7. - Comparison of ratios of rich-to-lean combustion stability limits for modules with different fuel injector locations.



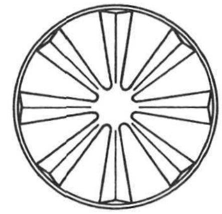
(a) Coiled strip (0.065-in. (0.159 cm) thickness, 0.5-in. (1.27 cm) width, 12-in. (30.5 cm length). Used with model 5 module.



(b) Coiled tube (0.125-in. (0.318-cm) diam., with solid cone in center, 0.375-in. (0.954-cm) diam. and height). Used with model 6 module.



(c) Tubing bundle (seven 0.5-in. (1.27-cm) tubes and six 0.375 in. (0.953 cm) tubes with lengths of 0.5 in. (1.27 cm)). Used with model 7 module.



(d) Radial V-gutter (0.0625-in. (0.158-cm) thickness, 0.375-in. (0.954-cm) width and depth of vanes). Used with model 8 module.

Figure 8. - Schematic diagram of four types of flame stabilizers.

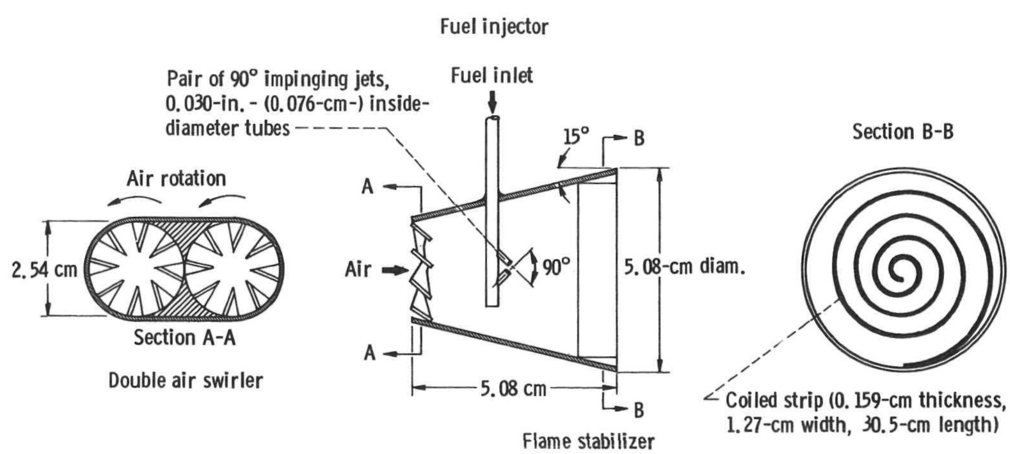


Figure 9. - Swirl-jet combustor module (model 5) used to test flame stabilizer designs. Coiled strip replaced with other designs shown in figure 9 for models 6, 7, and 8.

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